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Influence of rainfall and water level on inland fisheries production: A review

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ABSTRACT

Variation and shift in the seasonal pattern of the hydro-climatic factors is probably because of climate related changes. Rainfall, river inflow, snowmelt, and consequent fluctuation in water level are the hydro-climatic factors that influence the inland fisheries production worldwide. Increase in rainfall and water level favours the reproduction, recruitment and immigration of fish in the inland reservoirs. However, heavy rainfall and increased water level reduces the fish catch and the catch per unit effort (CPUE) significantly. During rainy season fish migrate to the newly inundated areas and shallow peripheries and escape from fishing gear because of the water level rise in the inland reservoirs. Reduction in CPUE also justify by the reduction in the number of fishers, boat, nets and fishing duration in the rainy days. Fingerling stocking and ceasing of fishing activities in rainy season are the common management practices in tropical countries like Sri Lanka. Climate change and consequent irregular rainfall pattern interrupt the inland fisheries production and management in capricious nature. Understanding the influences of climate changes in the hydro-climatic factors and predicting the future changes by modeling in a rational manner is mandatory for sustainable inland fisheries production.

Keywords: Rainfall; Water level; Inland fisheries.

INTRODUCTION

Inland fisheries are distinct from marine fisheries in their nature and hydro-climatic factors that influence its special and temporal distribution. Although commercially intensive fisheries exist, inland fisheries are generally characterized by small-scale/household-based activities. Production and catchability of fish in many aquatic ecosystems varies considerably as a result of seasonal, annual, inter-annual and decadal variability in their environment, known as climate variability [1]. Climate change is a significant and lasting change in the statistical distribution of weather patterns over periods ranging from decades to millions of years. It may be a change in average weather conditions, or in the distribution of weather around the average conditions and its affects the survival, growth, reproduction, and distribution of individuals within a species, but impacts can also be shown at the level of populations, communities, or entire ecosystems [1]. Impacts of climate change on aquatic ecosystems and associated livelihoods are affecting, and the purpose of this review is to provide information regarding the hydro-climatic factors and its influence on inland fisheries production.

Comparatively inland fisheries production is less (small-scale) than marine fisheries production. In 2012 inland capture fisheries production was 11.6 million tons and marine was 79.7 million tons [2]. Small-scale fisheries are gaining more global recognition as being integral to growth but also highly vulnerable to impacts linked to climate change. Especially inland aquaculture and capture fisheries production depend on the hydro-climatic influences. Commonly, heavy rainfall and the onset of water level rise in the inland reservoirs are the positive cues for the reproductive biology of fish. Considerable shift in the seasonality of hydro-climatic factors in a particular year affect the sustainable inland fisheries management.

2.0 NATURE OF HYDRO-CLIMATIC FACTORS

Major hydro-climatic factors of inland waters are rainfall, river inflow, snow melt and the water level of the reservoirs and other inland water bodies. Rainfall is the elementary hydrological factor affecting a whole chain of hydrological events, via runoff and river inflow to lake level [3]. There are several other factors such as air temperature increases (global warming), cloud cover, evaporation etc. affect these hydro-climatic factors directly and indirectly. Anthropogenic activities like irrigation, hydro-electricity, damming etc. also influence the hydrology especially on the water level of the inland waters (lakes and reservoirs). Seasonal variation in hydro-climatic factors tends to influence both catch and productivity of the reservoir [4]. Engagement of part-time fishers in agricultural and full time fisher's harvesting activities depends on the rainfall and other hydro-climatic conditions.

Daily rainfall data can be summed to obtain total rainfall of each month and daily water level data can be averaged to obtain the monthly mean water levels. These parameters can be used as the independent hydro-climatic factors in tropical low land reservoirs. Based on rainfall (monthly total), heavy, medium, low and very low quarters of the year could be categorized by using moving average techniques [5]. Similarly water level based quarters and semester wise categorizations (six month moving averages) can be used to analyze inland fisheries production.

2.1 World perspective

Over 75 % of earth surface is covered by water where marine and inland fishery production plays a substantial role in protein consumption globally. In 2012 Global inland waters capture production reached 11.6 million tons [2]. Inland fisheries in Asia are highly exploited and have very little room for expansion by better management. In Africa is still below the level experienced in Asia hence there still may be some potential for expansion. The economic value of small-scale fisheries in Africa could be doubled or tripled simply by improving post-harvest processing techniques. In Latin America, fisheries appear relatively less heavily exploited than in Asia, with few signs of fishing down at the community level, although some individual stocks are under pressure. Inland fish resources in Europe, North America and Australia are exploited more for recreational than consumptive purposes, and often managed to meet conservation objectives [6].

In Africa most of the inland water bodies are highly vulnerable to the climatic perturbations events have greatly influenced ecology, natural resources, and thus livelihoods. The main threat to Lake Chad in Africa and the people living in its basin is drought. However, the capacity to tackle and manage climate-related threats is hampered by poverty, weak political and economic stability, poor institutional capacity, and a limited knowledge base and information.

Couple of decades before, southern Africa has experienced a series of serious droughts which also greatly influenced the water levels of Lake Kariba which is located between Zambia and Zimbabwe. The hydrological regime of Lake Kariba, especially water level fluctuations, and the resultant nutrient inputs are important in promoting fish production.

2.1 Sri Lankan perspective

Sri Lanka is a tropical country which has the world's highest land: water body ratio. Total freshwater resources of the country are around 201,832 ha, which is ever increasing due to the construction of large and small reservoirs, mostly in the wet zone of the country in the recent past [7]. Considerable fluctuation of water level in shallow waters is a typical characteristic of the irrigation reservoirs in Sri Lanka [8].

There was a significant and positive correlation ($\rho=0.59$, $p < 0.05$) between monthly total rainfall and monthly average water level where linear regression showed that increase in monthly total rainfall by one mm increase the water level significantly by about 1.55 cm found in Sorabora reservoir, Sri Lanka in 2007 [5]. Moving averages of monthly total rainfall data showed that November to January quarter received the highest mean rainfall of 504.7 mm per month. Variation of water level in Sorabora reservoir closely follows the rainfall pattern. Additional increase in water level is partly due to the inflow of excess rain water from the catchment area, tributaries and canals. [5].

Regional hydro-climatic fluctuation is responsible for changes in the fisheries production in Vavuniya tank, Sri Lanka as well. Influences of rainfall changes on fish production in this reservoir is important because it was completely dried out since June to September 2012 and partially dried in August to September 2014. This was mainly due to irregular rainfall pattern and completes draining for agriculture, by using water pumps and tractor (Fig. 1). Subsequently it got refilled by monsoonal rains received from October 2012 onwards [9].

Fig. 1: Over extraction for irrigation from dead storage in Vavuniya tank, Sri Lanka

Consequences of irregular rainfall pattern shifted the heavy rainfall based quarter to the February-April quarter from November-January quarter in 2013 resulted low fish production. August–October and November-January quarters received low (99.5 mm/month) and lowest (45.0 mm/month) rainfall respectively in Vavuniya District, Northern province, Sri Lanka [9]. Hence, seasonal variation in the hydro-climatic factors plays a major role in inland fisheries production. Understanding the influences of changes in hydro-climatic factors in seasonal, annual and inter annual is mandatory for the sustainable management practices.

3.0 IMPACT OF CLIMATE CHANGE ON INLAND FISHERIES

Climate change is predicted to have major impacts on fish production [1], potentially influencing the economy of many developing nations worldwide [10]. Climate change has both direct and indirect impacts on fish stocks that are exploited commercially. Direct effects occurred through reduced rainfall and greater evaporation. Indirect effects when more water is used for irrigation to balance reduced rainfall. This kind of same phenomenon was observed in Vavuniya tank in Sri Lanka, 2013 (Fig. 1).

Direct effects act on physiology and behavior and alter growth, development, reproductive capacity, mortality, and distribution of fish community. Indirect effects alter the productivity, structure, and composition of the ecosystems on which fish depend for food and shelter.

Many inland fisheries are threatened by alterations to water regimes that, in extreme cases, cause whole lakes e.g., Lake Chad [11] and waterways to disappear. Threats to aquaculture arise from (*i*) stress due to increased temperature and oxygen demand and decreased pH, (*ii*) uncertain future water supply, (*iii*) extreme weather condition, (*iv*) frequent diseases outbreak and aquatic toxicity, (*v*) sea level rise and conflict of interest with coastal defenses, and (*vi*) an uncertain future supply of fishmeal and oils from capture fisheries [12] [13].

Inland fisheries are additionally threatened by changes in rainfall and water management. Some of the changes are expected to have positive consequences for fish production [14], but in other cases reproductive capacity is reduced and stocks become vulnerable to levels of fishing that had previously been sustainable [15]. Local extinctions are occurring at the edges of current ranges, particularly in freshwater and diadromous species such as salmon [16] and sturgeon [17]. Climate change can enable both competitive species, such as the Pacific oyster (*Crassostrea gigas*) [18], and pathogenic species to spread to new areas. Climate change has been implicated in mass mortalities of many aquatic species.

Aquaculture poses some additional threats to capture fisheries, and the development of aquaculture could affect the resilience of capture fisheries in the face of climate change [19]. There will also be some positive effects due to increased growth rates and food conversion efficiencies, longer growing season, range expansion, and the use of new areas as a result of decrease in ice cover. The frequency and intensity of extreme climate events is likely to have a major impact on future fisheries production in inland fisheries. Reducing fishing mortality in the majority of fisheries, which are currently fully exploited or overexploited, is the principal feasible means of reducing the impacts of climate change.

4.0 RELATIONSHIP BETWEEN HYDROLOGY AND FISH BIOLOGY

The biology of fish in the inland water bodies are highly influenced by prevailing hydro-climatic fluctuation of the region. These processes vary spacially and temporally. Spawning habits and natural recruitment of various fish species seem to be influenced by the hydro-climatic factors.

Variations in the intensity and duration of the floods and the severity of draw-down conditions during low water produce corresponding fluctuations in many biological parameters. Heavy rain causing flooding of terrestrial vegetation together with a change in water chemistry has been identified as ultimate cues for the spawning of cyprinids [20]. Gonad maturation and spawning of common carp in Victoria reservoir, Sri Lanka to be positively correlated with rainfall were observed by Nathenael and Edirisinghe who found that immature individuals were abundant during drier periods [21]. Horvath also showed that natural spawning of common carp is influenced by water temperature, rainfall and flooding [22].

During drier periods, silt deposition is known to increase mortality and decrease reproductive success [23]. Recovery of the fish stock occurs typically during the high water season, when fishing efficiency is low due to dispersion of fish in newly inundated areas. Dermersel fish species seems to be more affected by the expansion of water into shallow peripheries during heavy rainy days. The changes in the rainfall fluctuation significantly ($p<0.05$) influenced the species composition due natural recruitment and fingerling stocking in Vavuniya tank, Sri Lanka. Fingerling stocking and concurrent withdrawal from fishing activities during November – January is the common practices in Vavuniya.

Climate change and consequent irregular rainfall pattern shifted the heavy rainfall based quarter to the February-April quarter (from Nov-Jan quarter) in 2013 in Vavuniya tank, Sri Lanka. This situation favoured the irrational way of fingerling stocking and fishing activities indirectly. Fishermen continued fishing throughout the year which not allowed the stocked fingerlings to attain a suitable size. The maximum catch of *Oreochromis niloticus* was found in June and November but sudden drop occured in July, September and December. However, this phenominon occurred in opposite manner for *Channa spp.* and *Cirrrhinus mrigala* in Vavuniya tank, 2013 (Patrick *et al*., 2014). Natural recruitment depends on hydro-climatic factors, over exploitation in some parts other year could be avoided by efficient management.

Most species in Lake Kariba have their highest sexual activity coinciding with the rainy season (November-March) when the lake is rising [24]. In year 1967 and 1970 small amplitude in lake water level (approximately 2 m) with a high potential fish production. However, very great amplitude (6-8 m) in 1963 and 1969 were most possible responsible for a great decline in the potential fish production, the destruction of numerous cichlid nests. These findings seemed substantiated by Jackson and Donnelly who found that the 1958/ 1959 spawning of the Kariba tilapia, *Oreochromis mortimeri*, shortly after the dam closure, was successful to a previously unprecedented degree due to an increased food production and improved juvenile refuges in the impounded areas [25, 26].

In Lake Turkana, Kenya, where Kolding also found peak production years of tilapias associated with years of peak rises in the lake water level and a much stronger correlation between abundance indices and WL changes than absolute water level [27]. In order to achieve the maximum sustainable yield, rational understanding regarding the changes in hydro-climatic factors and its influences on the biology of local fish species is important.

5.0 CATCHABILITY AND HYDROLOGY

Many studies have shown that the hydro-climatic factors such as rainfall and water level in the reservoir affect the catch per unit effort (CPUE) as well as effort of fishers [4, 28, 29]. Rainfall and wind associated with changes in water level, waves, turbidity and water chemistry have proven to affect catch per unit effort (CPUE) in many inland reservoirs [4, 20, 29]. However, low rainfall could increase the catch and the effort by decreased the water level.

Moses showed that there exists a negative relationship between the water level and catch per unit effort in Nigerian reservoirs, indicating the difficulty of catching fish with expanded volume of water [4]. Kariba lake in Africa, inshore artisanal and offshore pelagic catch per unit effort time series fluctuate synchronously and show a remarkably high correlation with different time-lagged indices of water level changes, particularly water level rises. In contrast, there was a little or no correspondence with absolute water levels even during periods of drought. This finding seems to contradict earlier beliefs that fluctuating lake levels have an adverse effect on the fisheries and that the waters should be kept as stable as possible. Begg also recommended that, for Lake Kariba, "two metres annual lake level fluctuation appears the most suitable for fisheries management" [30].

Clear seasonal pattern in the hydro-climatic variables such as rainfall and water level are very strongly associated with the catch and effort statistics in the Sorabora reservoir, Sri Lanka has come to light. Multiple regression analysis of both rainfall and water level significantly influence the CPUE ($p<0.05$) and decrease in water level by one meter increased the CPUE by 0.42 kg /fisher/day and 0.4 kg /boat/day, when other effects of rainfall were held constant in Sorabora reservoir, Sri Lanka [5].

Rainfall seems to influence the catch and effort in multitude of ways. Rainfall tends to increase catch per unit effort directly causing turbidity and waves in the aquatic medium, while decreasing the same by increasing the water level of the reservoir. Distinct differences can be seen among fish species with respect to seasonality of catch statistics [5]. The effort statistics were also found to vary during the year with the rainfall pattern. Due to the possibility of high CPUE, more fisher tends to engage in fishing activities during the dry periods [31].

Complex effect of rainfall also cause unclear pattern with CPUE. Heavy rainfall could decrease the catch by expanding water into shallow peripheries. In Sri Lanka especially in Vavuniya tank, Sri Lanka fishing in the inundated area is difficult because of the vegetative cover that obstructs the fishing vessel (Canoe) operation. Usage of inflated lorry tubes / heavy vehicle's rubber tubes (modified fishing vessel) is the fisher's strategy to reach shallow peripheries of the tank for fishing when the water level exceeds fully supply level (Fig. 2).

Fig. 2: Usage of lorry tubes as simple fishing vessel in Vavuniya tank, Sri Lanka

According to the variations in the hydro-climatic factors the efforts and catches varies considerably. Hence, the catch was not distributed uniformly among the month, calendar year quarters and rainfall based quarters of the annum which was found to be significant for every species ($p<0.05$). When the monthly total rainfall increased, the monthly total catch decreased in Vavuniya tank. The catch was lowest (1 638 kg) in the heavy rainfall based quarter (February- April), when compared to other rainfall based quarters. August–October and November-January quarters received low (99.5 mm/month) and lowest (45.0 mm/month) rainfall respectively. Fish production reached the maximum level (4 676 -5 604 kg) when rainfall was lowest (Fig. 3) [9].

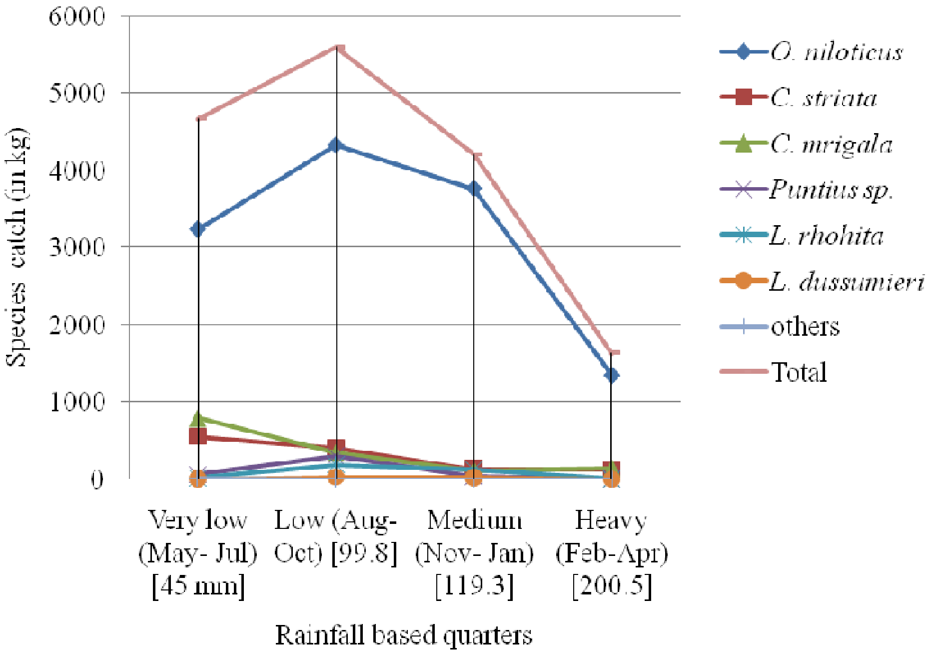

Fig. 3: Fish catch with rainfall based quarters in Vavuniya tank, Sri Lanka, 2013

This kind of findings also observed in Sorabora reservoir in Sri Lanka in 2007 where the rainfall seems to have a direct as well as indirect influence on the catch statistics. Water level of the reservoir is a better predictor variable of catch statistics. Many part time fishers involving in agriculture related activities are influenced by rainfall in many different ways. Therefore effort statistics are more influenced by rainfall when the role of part time fishers is high, as there are definite seasonal patterns of catch and effort statistics, reservoir management and planning must be conducted accordingly to achieve the highest sustainable harvest from the reservoir. Seasonal variation of hydro – climatic factors must be considered when initiating development programme in the reservoir.

CONCLUSION

Weather condition, seasonal fluctuation and climate change are the external environmental factors that driving the dynamics of inland water bodies globally. Shift in the seasonal variation of hydro-climatic factors such as irregular rainfall pattern, inflow and water level fluctuation occurring by means of climate related changes. Outbreak of human population and consequent anthropogenic activities are the major contributing cause for the climate change.

There is a strong relationship between the hydro-climatic factors and inland fisheries production worldwide. Seasonal pattern of the hydro-climatic factors are changing annually and inter-annually, due to the direct and indirect effect of climate change. Direct effects are reduced rainfall and greater evaporation act on physiology and behavior and alter growth, development, reproductive capacity, mortality, and distribution of fish community. Indirect effects when more water is used for irrigation to balance reduced rainfall which in turn draws down in water level even bellow the dead storage of reservoir (Fig. 1). These effects alter the productivity, structure, and composition of the ecosystems on which fish depend for food and shelter. Rainfall tends to increase catch per unit effort directly in the aquatic medium, while decreasing the same by increasing the water level of the reservoir. When the monthly total rainfall increased, the monthly total catch decreased. Rainfall tends to increase catch per unit effort directly. The effort statistics were also found to vary during the year with the rainfall pattern. Due to the possibility of high CPUE, more fisher tends to engage in fishing activities during the dry periods when the water level goes down.

Sexuality, reproductive potential and the natural recruitment of fish increase with rainfall and consequent water level rise of inland water bodies. Non-random distribution and abundance of fish species reflect in the catch statistics because of the seasonal variation of the year. Catch was not distributed uniformly among rainfall based quarters which was found to be significant for every species. Fingerling stocking and concurrent withdrawal from fishing activities during higher rainy seasons is common in the tropical countries. Climate change and consequent irregular rainfall pattern that shifting the heavy rainfall based quarter occasionally. This situation favoured the irrational way of fingerling stocking and fishing activities indirectly. Fishermen continued fishing throughout the year not allowed the stocked fingerlings to attain a suitable size (age at 1^{st} maturity) in Vavuniya tank, Sri Lanka 2013. Categorization of rainfall based quarters within the year and respect to its catch statistics are useful for efficient aquatic resource management in inland waters. Rational perceptive of climate change, resulted hydro-climatic factors and its influences on the fish biology and catchability will reach the maximum sustainable yield.

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